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Incorporating Engineering Specificity in the UTeach Observation Protocol

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Incorporating Engineering Specificity in the UTeach Observation Protocol

by

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Dedication

This effort and resulting report is dedicated to my wife Sarah and to my son Benjamin. Sarah is my best friend and the love of my life and I am finishing this report just in time to celebrate our 5th wedding anniversary. She has provided nothing but encouragement and support during my tenure as both a teacher and a student. Benjamin "Banjo" is the happiest boy that I have ever met and he napped just enough so that I could get some research and writing done during his amazing first year of life.

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Abstract

Incorporating Engineering Specificity in the UTeach Observation Protocol

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The University of Texas at Austin, 2014

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The UTeach Observation Protocol (UTOP) is designed to capture what occurs in a classroom. The UTOP was developed for use in the nationally recognized UTeach program (uteach.utexas.edu) and has been validated nationally in the Gates Foundation Measures of Effective Teaching. (http://www.metproject.org/downloads/Preliminary_Findings-Research_Paper.pdf)

Currently the UTOP has been used in both science and math classrooms and is being developed for use in English language arts and social studies classrooms as well. This report serves to begin the modification of the UTOP for use in an engineering classroom to evaluate engineering specific content.

The UTOP has been described as a lens for reflection on teaching practices and the goal of this report is to help focus that lens more clearly on the engineering classroom. This tool was created for utilization in both educator and administrator roles. Teachers can use the UTOP to self-assess their own teaching practices as well as in observing other teachers and identify classroom

best practices. Administrators and other classroom visitors can use the UTOP to understand and evaluate what occurs in a classroom for a multitude of outcomes.

The methodology chosen in this report to create the engineering specific examples used real lessons that have been implemented in engineering classrooms and vetted in actual practice. Using both initial lessons from the teachers and their feedback along with language taken from the Next Generation Science Standard *Framework* and the UTeach*Engineering* Engineering Design Protocol, the examples were developed to show how to score each indicator on a scale of 1 to 5, with 1 being the lowest and 5 being the highest score, in a secondary engineering classroom.

The next steps recommended for this work are to pilot the examples created in this report and test the usefulness of the examples created. This can be accomplished by field-testing it in UTOP training with teachers and modifying the information based on the feedback that they provide.

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Table of Contents

Chapter 1: Introduction

The burden today is on teachers to successfully prepare the students to enter the STEM talent pool. The preparation of students must be different for students entering undergraduate institutions in order to equip them to stay flexible and competitive. Brophy et al. (2008, p. 369) states “Much of the impetus for expanding engineering education in pre-kindergarten through 12th grade (P-12) in the U.S. stems from concerns about the quantity, quality, and diversity of future engineering talent.” It is important in this context to consider what educators can do and how they can be helped to improve student understanding of the engineering concepts and practices that will better prepare their students for the competitive 21st century engineering world.

The recent emergence of engineering education focused research leaves much room for study and improvement in the field. Application of engineering principles does not occur in a closed system and its practice has considerations in local, global, environmental, political, economic, societal contexts, to name a few. Students must be able to develop their understanding of these principles and practices, therefore, in variety of contexts. Constraints and context are critical issues for the modern engineer and educational programs should be equipped to produce an engineer who has the ability to consider the consequences of both. This begs the question of, “How can engineering programs best develop their students' ability to integrate context and design?” (Palmer, Terenzini, McKenna, Harper, & Merson, 2011, p. 1) Although the importance of engineering education is widely promoted, it seems like much of the current focus is on outreach “but it is questionable whether such outreach efforts are enough to attract the numbers of students needed in the field or if they can provide these learners with the experiences needed to succeed in the formal post-secondary engineering programs that they are being encouraged to pursue.” (Brophy, et al. 2008, p. 370)

In the broader context of Science, Technology, Engineering and Math (STEM) education, a large amount research, discussion, and initiatives is devoted to the math and science disciplines. We are knowledgeable of many aspects of what qualifies as good science and math instruction but the research base is not as evident in the engineering classroom. Johri and Olds (2011, p. 151) point out that, although “engineering education research has seen substantial growth in the last five years” it is lacking much of the theoretical frameworks and empirical findings that the learning sciences approach could supply. Although much of the theoretical foundation exists in science and math education, there is a shortage of learning science understanding in engineering education because so little research has been conducted on engineering education to date.

The UTeach Observation Protocol (UTOP) is currently being implemented in classrooms as “an observational instrument that can be used to assess the overall quality of classroom instruction in math and science from kindergarten to the undergraduate level.” (UTOP Training Guide, 2013, p.1) Although math and science specific examples of exemplary classroom practices exist in the UTOP training manual, engineering specific items do not. The general approach of this report will be to modify existing indicators in the UTOP observation protocol and to provide detailed engineering-specific examples for the Training Guide that can used to train observers as well as inform teachers about research-based practices for teaching engineering concepts to K-12 students. While much has been done in the fields of math and science in this area, engineering is just recently beginning to emerge as a larger educational priority in STEM.

Chapter 2: Review of Literature

When developing or improving any field it is important to keep best practices and the end goals in mind so that decisions and directions can be evaluated through that filter. Currently there are multiple examples of engineering education programs that make a concerted effort to use both classroom and engineering discipline best practices. One such program is UTeach*Engineering* and Marshall and Berland (2012) outline many of the goals, purposes, and best practices in their discussion of the program. One purpose of this program is for students and teachers to develop engineering understanding through engineering design challenges, which serve the purpose of integrating classroom best practices and engineering discipline best practices.

> In addition to emphasizing design, the commitment to engineering practice specifies an emphasis on engineering habits of mind. This focus grows out of our vision of going beyond educating future engineers, to supporting technological literacy and enhancing learning in other STEM fields. As such, we focus on engineering habits of mind— such as systems thinking, innovation and teamwork—over technological skills and deep exploration of math and science concepts that are traditionally associated with engineering." (Marshall and Berland, 2012, p. 41)

In order to develop effective "habits of mind" both students and teachers must develop conceptual knowledge of any content, and engineering is no exception. According to Streveler, et al. (2008), conceptual knowledge is central to engineering as a field and practice and is one important factor in preparing students for the engineering field. Conceptual knowledge plays a vital part in how we make sense of the world around us. Both quantities and relationships are part of conceptual knowledge in the engineering domain and understanding how students see and develop them is imperative to helping promote competence and expertise in engineering students. Conceptual knowledge is central to engineering as a field and practice.

Sheppard, Pellegrino, and Olds (2008) suggest three components of engineering practice that can be interpreted through an educational lens. Engineering practice is made up of many facets, including, but not limited to: problem solving, knowledge, and the integration of knowledge and process. They also argue that better understanding of students and teaching practices are vital aspects to improving the quality of engineering education. Understanding of how teachers influence the learning, knowledge and practice of their students should be developed and addressed.

Although a concerted push exists currently to improve STEM education, many times one or more of the four disciplines does not receive as much attention as others. Although “the STEM fields are collectively considered core technological underpinnings of an advanced society, according to both the National Research Council and the National Science Foundation” (Marshall & Berland, 2012) much more is known about students in the science and math classrooms.

Engineering can help fulfill many of the goals of overall STEM education. Brophy et al. (2008) consider how relevant engineering education and content to attaining STEM education goals and benchmarks. Their paper also “explores how engineering education can support acquisition of a wide range of knowledge and skills associated with comprehending and using STEM knowledge to accomplish real world problem solving through design, troubleshooting, and analysis activities.” (Brophy et al. 2008).

Observation protocols can serve to evaluate how well the engineering coursework and teaching practices are helping students to fulfill the STEM education goals in a specific classroom. There are multiple facets and issues to consider when evaluating the effectiveness of engineering practice in the classroom. VanTassel-Baska et al. (2007), discuss many of the complexities of teaching. They state that it is a complex societal interaction requiring multiple levels of thought, decisions, strategies, objectives etc. With all of this considered they state that although teaching has traditionally only involved the teacher with students, “improvement in teaching clearly requires a change in teacher behaviors that promote learning in students. Such improvement appears to imply the use of higher order thinking, problem solving, and metacognitive approaches. In order to ensure that teachers are employing such strategies, some form of monitoring teacher behaviors must occur.” (VanTassel-Baska, Quek, and Feng, 2007, p. 4).

Observational protocols can serve as a method to improve classroom best practices. This can occur through a variety of mechanisms, but when a teacher receives feedback about their classroom from someone who is trained on a validated protocol that is designed to capture what is going in in the classroom, the teacher is able to engage in a more meta-cognitive approach in their classroom. As Black and Wiliam (2001, p. 1) put it, “Learning is driven by what teachers and pupils do in classrooms.” Standards in engineering education, all education for that matter, can only be improved if teachers can tackle what occurs in the classroom more effectively. This was recognized during the TIMSS video study: "A focus on standards and accountability that ignores the processes of teaching and learning in classrooms will not provide the direction that teachers need in their quest to improve." (Stigler and Hiebert 1997, pp. 19-20).

Teachers need practical insights and methods to improve what learning is occurring in their classroom. “It is critical to consider what is being done, and what might be done, in the educational system prior to college to improve outcomes of the P-12 educational process, especially regarding the engineering profession.” (Brophy, et al. 2008, 1) We therefore expect, in the context of this report, that providing teachers with authentic assessments of their engineering instruction will be useful in the context of both student and teacher understanding and development.

Chapter 3: Methods

The UTOP Instrument indicators that will be the focus of this report were developed by modifying the existing Classroom Observation Protocol (COP, Horizons Research, 2000) from Horizon Research to incorporate UTeach educational philosophy, expectations, and best practices. Four sections were modified: “Classroom Environment, Lesson Structure, Implementation, and Mathematics/Science Content. Each of the 4 sections concluded with a 1-5 Synthesis Rating which was intended to capture the observers ’ overall rating of the teaching behaviors in that section, without necessarily being a numerical average.” (Walkington & Marder, 2013, p.3)

The UTOP began in 2006 and over the past 6 years continual modifications and adjustments to the indicator language were made in response to observations made by teams of graduate students – for example, using the protocol to observe teachers in the Noyce Study, it was recognized that observers must be classroom teachers with depth of content knowledge and pedagogy specific to the subject and grade-level taught. (Development of the UTOP, p. 3) The developers created initial face value and revisions during the Noyce studies conducted from 2006 – 2010. (Marder, 2010) The creators then used several video segments from the Measures of Effective Teaching Project (MET) video library (Ibid, p. 6) teachers to establish validity of the protocol with appropriate training by 100 trained observers viewing approximately 1000 videos.

Concurrently, the training manual is structured to contain a description of each indicator, a general scoring rubric, and specific examples of each score for each indicator as it might be observed in a mathematics or science classroom. Since 2011 the program has used observational data and teacher feedback from the math and science teacher participants to continually improve the language for clarity and usefulness in implementation.

Building upon this foundation, this report will serve to create a first draft of the Engineering UTOP content indicators (for Domain 4, Content) by modifying or adding to existing Math and Science indicators as needed. Secondly, specific examples from an engineering classroom will be developed to reflect what each indicator score (1-5) will look like for the training manual.

The Framework for K-12 Science Education defines the teacher and student classroom practices that meet the Next Generation Science Standards (NGSS) and will be used to develop the engineering specific language and indicators for the UTOP. The Framework document supporting the NGSS implementation was chosen because these new standards were developed primarily for use in K-12 classrooms, which align with the scope of this report in modifying the UTOP for use in engineering, pre-college classrooms. The NGSS is widely recognized in education and can help facilitate the understanding of engineering education through the lens of the UTOP. The first step in developing the NGSS was the framework previously mentioned. "The *Framework* was a critical first step because it is grounded in the most current research on science and science learning and identified the science all K-12 students should know." (NGSS, Development Overview)

The following is from Appendix F: Science and Engineering Practices in the NGSS.

> "The eight practices of science and engineering that the Framework identifies as essential for all students to learn and describes in detail are listed below:
>
> 1. Asking questions (for science) and defining problems (for engineering)
> 2. Developing and using models
> 3. Planning and carrying out investigations
> 4. Analyzing and interpreting data
> 5. Using mathematics and computational thinking
> 6. Constructing explanations (for science) and designing solutions (for engineering)
> 7. Engaging in argument from evidence
> 8. Obtaining, evaluating, and communicating information"
>
> (NGSS, 2014)

(See Appendix 2 for a comparison between the NGSS Framework and the UTOP content section)

Figure 1 – Uteach*Engineering,* Engineering Design Process, 2014

The next step of the report was to compare the engineering practices in the NGSS Frameworks to the language in the UTeach*Engineering* Engineering Design process (Figure 1,p. 11). This process was chosen because, unlike in the NGSS, the practices are engineering specific and not combined with science practices. As a result, it will allow for a comparison to differentiate between practices that are applicable specifically to science classrooms and those that are specific to engineering classrooms. Another motive for selecting this specific process is that the teachers asked to provide exemplar lessons are all familiar with this specific EDP from UTeach and use it, or some iteration of it in their own classrooms.

In the context of this report the following quote was considered: "The end-products of science are explanations and the end-products of engineering are solutions." (NGSS *Framework*, Appendix F, p.27). This, along with the UTeach*Engineering* EDP was used to evaluate the NGSS Science and Engineering Practices to differentiate between those that specifically evaluate engineering and those that specifically evaluate science.

Finally, in order to provide these engineering examples some face validity in the classroom, the new engineering indicators were sent to several in-service teachers that have experience teaching engineering in the middle and secondary classroom. This step was implemented in order to get their feedback on the indicators and how well they represented an actual engineering classroom. They were also asked to provide examples of lessons that might be applicable to the specific indicators in order that the examples created in this report might be based on actual classroom lessons. This serves to better validate the indicator descriptions and engineering specific examples based on the general rubric as well as to differentiate them from the examples for science and math instruction. Using both the language from the NGSS Framework and the UTeach*Engineering* EDP, these teacher-provided lessons were modified to show examples of what the general rubric might look like it its implementation.

Chapter 4: UTeach Observation Protocol Engineering Modification

Engineering—Section 4

4.1 Content Significance: The **engineering** content chosen was significant, worthwhile, and developmentally appropriate for this course (includes the content standards covered, as well as examples and activities chosen by the teacher).

In this item, the emphasis on *worthwhile* captures the degree to which important **engineering** ideas are central to the lesson. Since the significance of content is highly context-specific and based upon the intended goals of the course being observed, the rater should rely on his or her judgment as an expert in the content area in order to determine whether the content was truly worthwhile for the students. Further, the rater should use knowledge of applicable national and state standards, as well as the developmental appropriateness (i.e., whether it is appropriate for the grade level of the class) of the content presented. Beyond just considering the content’s connectedness to accountability standards, the rater should consider the significance of the examples and activities the teacher used to cover these standards, and whether these examples incorporate worthwhile **engineering** concepts appropriately.

General Rubric

1. This item should be rated a 1 if the content covered and/or tasks, examples, or activities chosen by the teacher were unrelated to the **engineering** content of the course.
2. This item should be rated a 2 if the content covered and/or tasks, examples, or activities chosen by the teacher were distantly or only sometimes related to the **engineering** content of the course. This item should also be rated a 2 if the content chosen was developmentally inappropriate—either too low-level or too advanced for the students.
3. This item should be rated a 3 if the content covered was significant and relevant to the **engineering** content of the course, but the presentation, tasks, examples, or activities chosen were prescriptive, superficial, or contrived and did not allow the students to make meaningful connections to **engineering** ideas.
4. This item should be rated a 4 if the content covered and/or tasks, examples, or activities chosen by the teacher were clearly related to the significant **engineering** content of the course, and the tasks, examples, or activities that were used allowed for some student development of worthwhile connections to the **engineering** ideas.
5. This item should be rated a 5 if the content covered and/or tasks, examples, or activities chosen by the teacher were clearly and

explicitly related to significant **engineering** concepts in ways that allowed students to gain a deeper understanding and make worthwhile connections to the **engineering** ideas.

Specific Examples of Supporting Evidence (Engineering)[1]

1. The teacher showed the movie *Flight of the Phoenix* to a 9th grade engineering class while she sat at her desk not interacting with the students. No guidelines for viewing or discussion of how the movie related to the content, concepts, or specific objectives of the course were provided. Some students watched the movie, while others had their heads down on their desks or chatted/texted each other.
2. The teacher gave her freshmen engineering students patents and schematics of an airfoil taken from a graduate level aeronautical engineering and design course with no introduction or scaffolding. She told the students that she wanted to see if they could figure out how an airplane wing works based only on these advanced drawings. Although a few students worked diligently, most of the students were openly confused and had difficulty participating in the activity.
3. The teacher told the class that the objectives for this lesson were for them to be able to understand how wings create lift, what principles

[1] This example was created using the Airfoil Design Challenge Project linked below. Used with permission of the teacher.
https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxsb2dhbnBlYXJjZWVkdWNhdGlvbnxneDo1ZWEwZmNlMDRkNGU3OTVj

govern the effectiveness of a wing, and what factors can be manipulated to improve the ability of a wing to produce lift. The teacher said that they needed to know this material to do well in the future of this class and in later physics classes.

4. Given the task of designing a wing, the students based their decisions upon the notes that they covered in class and interviews with aeronautical engineers and customers, provided by the teacher. The students then designed their own wings using the engineering design method developed for use in this high school freshmen classroom by the department. They made several iterations of their wings and then placed them in the class air-tunnel and tested the design for lift. The students shared their results but did not discuss their design justifications.

5. Over the course of several weeks, students gathered, read and evaluated technical information from multiple authoritative engineering resources and used those resources to justify their design choices on a wing. The students then designed their own wings using the engineering design method designed for use in a high school freshman classroom. They made several iterations of their wings and then placed them in the class air-tunnel and tested the design for lift. The students shared their results and their design justifications from their engineering-notebooks and made

recommendations for future changes of the design based on tests from the rest of the class.

4.2 Content Fluency: Content communicated through direct and non-direct instruction by the teacher is consistent with deep knowledge and fluency with the **engineering** concepts of the lesson (e.g., fluent use of examples, discussions, and explanations of concepts, etc.).

This indicator assesses the degree to which the teacher demonstrates deep knowledge and fluidity with the content, as evidenced by the teacher giving detailed and clear explanations, using the big ideas of the content area as a unifying theme, calling attention to applications of the concepts being taught, and fluidly using examples and connections within the subject area. The teacher's depth of subject matter knowledge can also be assessed by observing how his or her understanding of student mistakes, common misconceptions, or alternative ways of thinking about and solving problems is used to help build student knowledge. The teacher's fluency with the discipline can also be evidenced by skillful facilitation of group discussions using probing questions to guide students' thinking, as well as the ability to give clear and, if needed, multiple examples and to use different methods for the explanation of concepts.

General Rubric

1. This item should be rated a 1 if there was a significant issue with the teacher's understanding and/or communication of the content that negatively impacted student learning during the class period.
2. This item should be rated a 2 if there were several smaller issues with the teacher's understanding and/or communication of the content that sometimes had a negative impact on student learning.
3. This item should be rated a 3 if there were no issues with the teacher's understanding of the content and its accuracy, but the teacher was not always fluid or did not try to present the content in multiple ways. When students appeared confused, the teacher was unable to reteach the content in a completely clear, understandable, and/or transparent way such that most students understood.
4. This item should be rated a 4 if the teacher clearly understood the content and how to successfully communicate the content to most students in the class. The teacher used multiple examples and strategies to engage students with the content. The teacher's depth of content knowledge enhanced student learning.
5. This item should be rated a 5 if the teacher clearly understood the content and how to successfully communicate the content to *all* students in the class. The teacher was able to present interesting and relevant examples, explain concepts in multiple ways, facilitate

discussions, connect the content to the big ideas of the discipline, use advanced questioning strategies to guide student learning, and identify and use common misconceptions or alternative ideas as learning tools. The teacher's depth of content knowledge greatly enhanced student learning.

4.2 Content Fluency: Content communicated through direct and non-direct instruction by the teacher is consistent with deep knowledge and fluency with the **engineering** concepts of the lesson (e.g., fluent use of examples, discussions, and explanations of concepts, etc.).

This indicator assesses the degree to which the teacher demonstrates deep knowledge and fluidity with the content, as evidenced by the teacher giving detailed and clear explanations, using the big ideas of the content area as a unifying theme, calling attention to applications of the concepts being taught, and fluidly using examples and connections within the subject area. The teacher's depth of subject matter knowledge can also be assessed by observing how his or her understanding of student mistakes, common misconceptions, or alternative ways of thinking about and solving problems is used to help build student knowledge. The teacher's fluency with the discipline can also be evidenced by skillful facilitation of group discussions using probing questions to guide students' thinking, as well as the ability to give clear and, if needed, multiple examples and to use different methods for the explanation of concepts.

General Rubric

1. This item should be rated a 1 if there was a significant issue with the teacher's understanding and/or communication of the content that negatively impacted student learning during the class period.
2. This item should be rated a 2 if there were several smaller issues with the teacher's understanding and/or communication of the content that sometimes had a negative impact on student learning.
3. This item should be rated a 3 if there were no issues with the teacher's understanding of the content and its accuracy, but the teacher was not always fluid or did not try to present the content in multiple ways. When students appeared confused, the teacher was unable to reteach the content in a completely clear, understandable, and/or transparent way such that most students understood.
4. This item should be rated a 4 if the teacher clearly understood the content and how to successfully communicate the content to most students in the class. The teacher used multiple examples and strategies to engage students with the content. The teacher's depth of content knowledge enhanced student learning.
5. This item should be rated a 5 if the teacher clearly understood the content and how to successfully communicate the content to *all* students in the class. The teacher was able to present interesting and relevant examples, explain concepts in multiple ways, facilitate

discussions, connect the content to the big ideas of the discipline, use advanced questioning strategies to guide student learning, and identify and use common misconceptions or alternative ideas as learning tools. The teacher's depth of content knowledge greatly enhanced student learning.

Specific Examples of Supporting Evidence (Engineering)[2]

1. The teacher's lecture on a customer needs analysis was very confusing. He kept correcting himself and changing what he was saying about the concept while constantly referring to his notes. The teacher did not check to see whether the students understood, and his explanations were disorganized and unclear.

2. The teacher was able to clearly lead his students through the steps of a customer needs analysis by closely following the curriculum guide, but had a hard time answering questions that the student had about interviewing customers and how they should frame the questions. He didn't seem to know how to explain the purpose or intended outcomes of process when the students were confused or had issues with understanding.

3. The teacher effectively and efficiently led the class through an example of a customer needs analysis on the board starting with identifying the customer, providing example interview questions, and

[2] This example was created based upon an interview with an engineering teacher who has taught the Engineer Your World Curriculum from UTeach*Engineering*. Used with permission of the teacher.

then organizing them into categories to be analyzed. When students had questions, he led them through the the same framework again with careful emphasis on each step but was unable to explain why each step was important or give other examples of the concept that might connect it to previous topics or discussions in the class.

4. The teacher began the lesson on customer needs analysis by asking questions of the students about what an engineer needs to know from the customer when designing a product. He was able to both ask probing questions of the students to check their understanding of underlying ideas and answer most questions that the students had with real-world examples even if the question was not related to the prepared content for that day. The teacher seems to have a lot of knowledge about how professionals apply knowledge of customer needs to the engineering field and integrated the discussion throughout the lesson.

5. The teacher began a lesson on customer needs analysis with a warm up activity that assessed student's ability to identify constraints and clarify problems in a product redesign and identify example questions that might help to clarify ideas. Once most of the students demonstrated understanding of the concepts the teacher introduced the idea of interviewing customers and developing questions that are broad enough to allow a customer to tell them what they need in a product. The teacher gave each group an

example scenario to work on, monitored group work and used the student-created responses to correct any mistakes. He was consistently able to use multiple real-world examples to explain the concept in more than one way.

4.3 Content Accuracy: Teacher written and verbal content information was accurate.

Written content information can include information provided by the teacher on tests, quizzes, worksheets, handouts, dry erase boards, PowerPoint presentations, overheads, etc. Verbal content information is anything the teacher says out loud during the class period. Since it is essential that content information be communicated in a clear, accurate, and unproblematic manner, this item assesses the teacher's ability to provide accurate written and verbal content information.

In mathematics, an example of ambiguous or unclear written content that would be applicable to this indicator would be if the teacher used the same letter to represent two different variables in the same problem. If no errors, ambiguities, or other issues are observed in the written or verbal content information of the lesson, this indicator should be rated as a 5. If there are errors with the written or verbal content of the lesson, the rating for this indicator may be reduced based on the severity of the violation of content accuracy and/or the level of ambiguity. When considering worksheets, it does not matter whether teachers actually wrote the content information themselves; they are responsible for the accuracy and clarity of the written content communicated during the class period. This indicator does not include written content in a textbook. As shown on the rubric, it is important to note whether the mistake was caught and corrected when determining a rating.

General Rubric

1. This item should be rated a 1 if there was a major instance of incorrect written or verbal content information communicated by the teacher that was not corrected, and this mistake had a large negative impact on student learning.
2. This item should be rated a 2 if there was a major instance of incorrect written or verbal content information that the teacher caught and corrected, or if there were a number of minor written or verbal content mistakes, inconsistencies, and/or ambiguities that negatively impacted learning.
3. This item should be rated a 3 if there were minor written or verbal content issues, and the teacher did not correct or catch all of them.
4. This item should be rated a 4 if there were only minor content mistakes or ambiguities that were corrected by the teacher.
5. This item should be rated a 5 if there were no examples of incorrect or ambiguous written or verbal content information communicated by the teacher during the class period.

Specific Examples of Supporting Evidence (Engineering)[3]

1. The teacher was using a power point for the lesson that was interchanging and confusing key vocabulary words: concept, sketch, working drawing, model, and working prototype. The teacher then showed a picture of a working prototype of a puzzle cube while referring to it as a sketch and telling the students that they would be creating sketches like what is seen on the board for the project.
2. At the beginning of the lesson the teacher referred to a working prototype of a puzzle cube as a working drawing. When a student eventually mentioned the mistake, the teacher seemed to know what the student was talking about and corrected himself.
3. The teacher gave students a rubric for their puzzle cube project that used a few of the words like sketching, and multi-view drawings interchangeably even though these terms are used to represent different stages in engineering design process. The teacher then attempted to alter the rubric. The alterations still had some mistakes in them and the students were left confused because they were not corrected.
4. There were a few minor mistakes in the wording of the rubric that was handed to the students. While going over the rubric with the

[3] This example was created based upon an interview with an engineering teacher who has taught the Project Lead The Way Curriculum. Used with permission of the teacher.

students these mistakes were corrected by the teacher, and all other written content information was accurate.

5. The PowerPoint slides presented over modeling and prototyping were correct. The rubric was clear and well organized and allowed the students to compare, integrate, and evaluate the concepts in the lesson. There were no examples of verbal or written inaccuracies during this lesson.

4.4 Content Assessments: Formal assessments used by teacher (if available) were consistent with content objectives (homework, lab sheets, tests, quizzes, etc.).

A formal assessment is interpreted as any work by the student that the teacher either collects for later evaluation or checks for correctness during the class period. Formal assessments can include homework assignments, group assignments, lab sheets, tests, quizzes, and worksheets, as well as teacher rubrics for student presentations, papers, or projects. This indicator measures how well the formal assessments are aligned with the objectives of the instruction. The degree to which the content is covered, in what depth, and with what emphases should all be considered when evaluating the quality of the formal assessments.

An NA should be chosen in the case where the teacher uses no formal assessments during the lesson.

General Rubric

1. This item should be rated a 1 if there was a formal assessment given during the lesson, but this formal assessment was highly inappropriate and not matched with the content objectives.
2. This item should be rated a 2 if there was a formal assessment during the lesson, but the assessment was poorly designed or not entirely consistent with content objectives.
3. This item should be rated a 3 if there was a formal assessment during the lesson, and this formal assessment was generally appropriate and matched with content objectives.
4. This item should be rated a 4 if there was a formal assessment during the lesson, and this formal assessment was well designed to evaluate student understanding of important **engineering** concepts that had been central components of instruction in the classroom.
5. This item should be rated a 5 if there was a formal assessment during the lesson, and this formal assessment was well designed to evaluate student understanding of important **engineering** concepts that had been central components of instruction in the classroom. The assessment was also designed to push students' thinking to the next level and provide opportunities for challenge and additional learning.

Specific Examples of Supporting Evidence (Engineering)[4]

1. The students were finishing up a robotics project and given an exam over gear ratios, material that the students complained had not been covered in class yet and had nothing to do with their project. The teacher just asked the students to do their best and quietly complete the test.
2. The students were given a test over command and control software concepts that the class had just finished that seemed to be too difficult for students. After multiple students raised their hands and said they did not understand the questions the teacher responded by allowing them to use their notes to finish the exam.
3. The teacher gave the students an exam over the project that had just finished over robotics. The test was derived from their notes and seemed to be in line with the standards and objectives being covered in class. There was some confusion with how to answer the questions, but the teacher provided support and answered the students' questions so that they could complete the assessment and turn their papers in at the end of class.
4. The teacher gave the students a mid-project assessment over gear ratios and the command language that they had been using in their robotics project. The students were given a paper with guidelines for

[4] This example was based on a teacher-created quiz over robotics and programming that has been used in the classroom. Used with permission.

where a robot should move. The students were then given a robot and asked to program the robot to move around the class and then return to its starting position in the order that the instructions were given. They were then asked to calculate the seconds/degrees/rotations needed for each turn and then have the robot return to its original location. The exam provided clear instructions for the process, but left open choices about several operations to be completed. This exam assessed the students' conceptual knowledge and application of several important concepts from the project.

5. The teacher gave the students an mid-project assessment over the project that had just finished over robotics. The students were given a paper with guidelines for where a robot should move. The students were then given a robot and asked to program the robot to move around the class and then return to its starting position in the order that the instructions were given. They were then asked to calculate the seconds/degrees/rotations needed for each turn and then have the robot return to its original location. After the robot returned to its starting point, the students were asked to design an interpretive dance for the robot with their group. They were told to use several steps of the engineering design process to have the robot perform a dance in the classroom using its movement programming. The

students were told that they would need to use everything they had learned from the project to accomplish their goal.

4.5 Content Abstraction: Elements of **engineering** abstraction were used appropriately (e.g., multiple forms of representation in **engineering** classes include verbal, graphic, symbolic, visualizations, simulations, models of systems and structures that are not directly observable in real time or by the naked eye. These may include: functional models, design drawings, CAD models, concept generation methods, etc.)

This indicator captures how well the teacher facilitates conceptual understanding by representing relationships or patterns in abstract or symbolic ways. Moving toward abstraction can assist students in understanding the content as a coherent and integrated whole, as opposed to a set of facts, procedures, or vocabulary terms. Abstraction can lead students to see the “big picture” and connections between important concepts in the discipline. In engineering, abstraction is often represented by the modeling of complex systems to capture and focus the customer needs in context of the constraints upon the problem or solution. This may include: black-box modeling, customer- needs analysis, functional modeling etc.

A rating of 3 is the default score for this indicator, if you notice nothing especially good or especially poor about the use of abstraction. It is important when awarding a high score (4 or 5) on this indicator is to consider whether the abstraction is being used for a relevant and useful purpose; for example, are students simply drawing inputs and outputs of a system because it is part of a school exercise, or are they developing a black box model to help them understand how inputs and outputs relate to a system in to help them accomplish some larger, more authentic goal?

An NA is an appropriate rating for lessons where abstraction of or generalization to complex systems does not arise for appropriate reasons related to the lesson purposes; for example, if the class is focused on data collection for a lab activity, it is unlikely at that point in the learning sequence that abstraction would be appropriate. Thus if abstractions were not included in the lesson, but you feel this lack of inclusion was an appropriate instructional decision, rate this indicator NA.

Engineering-Specific Instructions

This indicator captures how well the teacher facilitates deeper understanding by choosing activities or design challenges that prompt students to make connections between important concepts beyond the immediate scope of the lesson. For example a teacher might use the process of toasting bread to have students analyze and evaluate the inputs and outputs in a black-box model (See Table X). With such an activity it is important that the teacher make explicit that this is a model of a complex process that does not occur in a closed system.

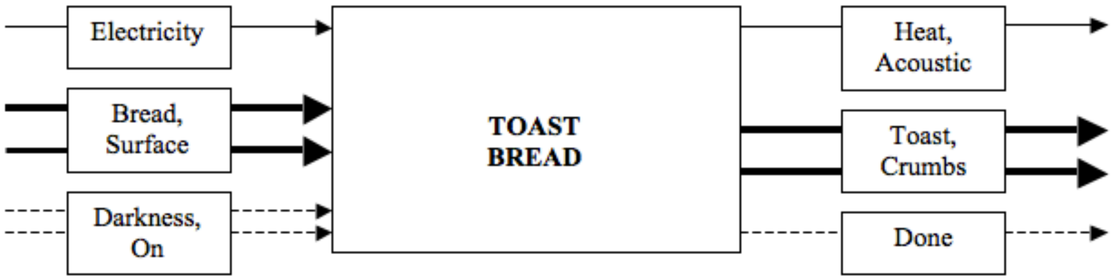

Figure 2: modified from UTeach MASEE program curriculum: Black Box Model for Toasting Bread http://www.uteachengineering.org

General Rubric

1. This item should be rated a 1 if there was a major issue with the teacher's use of abstraction that had a negative impact on student learning during the class period.

2. This item should be rated a 2 if the teacher neglects important explanation and discussion of abstraction that is being used during the class period, and this missed opportunity has a negative impact on student learning.

3. This item should be rated a 3 if the teacher's use of abstraction was adequate—the teacher allows for some discussion or explanation, and does not use abstraction inappropriately.

4. This item should be rated a 4 if abstraction is used during the class period for a relevant and useful purpose. The teacher should explicitly engage students in some discussion of the meaning of the

representation, and/or should successfully connect different representational forms. Perhaps there was a small missed opportunity with respect to facilitating some students' understanding of abstraction.

5. This item should be rated a 5 if abstraction is being used for a relevant and useful purpose, like modeling or justifying an engineering design decision, AND if the teacher engages students in a discussion of the meaning and purpose of the representation. The abstractions are presented in a way such that they are understandable and accessible to all students in the class.

Specific Examples of Supporting Evidence (Engineering)[5]

1. The teacher introduced the students to patent images and diagrams of propellers with multiple perspectives. There was no discussion about what the images meant or their purpose. The students were confused and unable to understand the images, the meaning, or their purpose.

2. During a lesson about propeller design the students are asked explicitly to read customer interviews about what they need or want from a propeller and create a customer-needs analysis with metrics to evaluate the needs; however, the teacher told the class to skip

[5] This example was created using the Propeller Design Challenge Project linked below. Used with permission of the teacher.
https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxsb2dhbnBlYXJjZWVkdWNhdGlvbnxneDoxZjUyZGM5Yzk2NmY1OTIy

this part of the activity and some students were confused about why customer interviews were needed or what they meant.

3. Abstraction seemed to be used adequately in this lesson. Students, in their groups were tasked with reading teacher-created “customer interviews” and then creating a customer-needs analysis. They then developed a needs-metric table to determine in what units the customer needs may be measured. The students seemed to have a good understanding of what units would be needed to measure an output (e.g rpm – revolutions per minute – for propeller speed)
4. Students were collecting data on propeller designs using models to determine optimal design solutions. The students input their data into a simulated computer program where the constraints and design factors could be manipulated to test effects. They were using their symbolic representations for a relevant and practical purpose and the teacher briefly discussed with the students what the models, graphs and data meant. However, this discussion could have been more accentuated as an integral part of the class and engineering practice.
5. Students were collecting and interpreting data on propeller designs using models to determine optimal design solutions. The students input their data into a simulated computer program where the constraints and design factors could be manipulated to test effects. The teacher then guided them to use the data to compare and

analyze how well various designs met specific design criteria. Models and the symbolic representations of the data were used for a relevant and practical purpose as they continued to develop their understanding of the designs and justify possible design decisions. Throughout the lesson there was student and teacher discussion about the realistic meaning and purpose of the models and its applicable data.

4.6 Content Relevance: During the lesson, it was made explicit to students why the content is important to learn.

This indicator assesses the degree to which the teacher explicitly placed the content into the big picture of the associated discipline, making it clear why these concepts are significant and important to learn. This indicator may be evidenced by the teacher discussing the significance of the content with the students during the class period or giving the students activities that explicitly bring out the big picture and/or significance of the material and facilitate students' understanding of why this content is fundamental. One example of such a strategy would be focusing student work for a given week through several guiding questions about why the class is learning the content. If the teacher simply gives the students some problems that happen to be contextualized, this is not the same thing as engaging students in a discussion about why they are learning the content, and thus is not important evidence for this indicator. Also, simply telling students that they need to learn the content for future classes, future topics in this class, or for a test is not what we are trying to capture with this indicator.

Although it may seem inappropriate to penalize a teacher for not incorporating this indicator into every single lesson, it is important that we identify the degree to which these behaviors are present. If there is absolutely no mention or discussion of why the content being covered during the lesson is important to learn, this indicator should be rated as a 1. The indicator should be rated a 1 in this situation even if you feel such discussion would not be appropriate or possible for this particular lesson.

General Rubric

1. This item should be rated a 1 if there were no instances of it being made explicit to students why the content is important to learn.
2. This item should be rated a 2 if the teacher made only a brief reference to the importance of the content, and there was no elaboration or discussion. This item should also be rated a 2 if the teacher did not explicitly discuss content significance, but the significance was clearly implicit or obvious in the work students were doing.
3. This item should be rated a 3 if the teacher made some moves to tie in the significance of the content during the class period, perhaps mentioning it more than one time.

4. This item should be rated a 4 if the teacher engaged students in a discussion of why the content was important to learn.
5. This item should be rated a 5 if the importance of the content was a central theme that was discussed and expanded upon throughout the class period.

Specific Examples of Supporting Evidence (Engineering) [6]

1. This lesson was about how different parameters and constraints of influence the design of musical instruments; however, the teacher did not connect the lesson to why it was important to learn about these concepts in engineering or science fields.
2. The teacher built on the previous day's lesson on the constraints in the design of the musical instruments chosen for the class' project. The teacher briefly mentioned that these concepts are used by engineers to develop their designs to solve a problem but did not elaborate on the process during this class period.
3. The teacher had a guiding question on the board for the week which was "How can design constraints be determined scientific principles and customer needs?" The teacher mentioned the question while in discussion with the students at two points. They then got onto a musical instrument website and evaluated design decisions on

[6] This example was based on a project that a science/engineering teacher created for use in her class. This project is for a science classroom but the students follow the engineering design process to develop their own musical instrument to play an 8-note scale as accurately as possible. Used with permission from the teacher.

guitars for customer preference and. scientific principles that influence acoustics. Although the activity was engaging and clearly relevant, the teacher did not make explicit how what they were doing was important to the engineering discipline and practice.

4. The teacher used the guiding question “How can design constraints be determined by scientific principles and customer needs?” to launch a multiple day activity about the science of sound and how to use the engineering design process to apply the scientific principles to create their instruments. She also used examples of how ergonomics and other customer needs can limit what an engineer can actually design because instruments are designed for customers based on aesthetics as well as science. They then got onto a musical instrument website and evaluated design decisions on guitars for customer preference and scientific principles that influence acoustics.

5. The teacher invited local musicians into the classroom and told the students that this is a chance to apply both scientific principles and customer needs to a real situation. The students were tasked with developing instruments for the musicians to actually use at a benefit concert in town. They were told that they would have to balance their scientific knowledge with what their customers needed and that the musicians would decide if they would play the student-created instrument at the concert. During the lesson that was observed the

teacher led a discussion about how the students as engineers might have some trade-offs in their design and how this idea applies to the entire engineering field. They also discussed how advances in science make analysis of proposed solutions more efficient and effective.

4.7 Content Interconnections: Appropriate connections were made to other areas of **engineering** and/or to other disciplines.

Connecting **engineering** concepts across the disciplines tends to generalize the content and make it more coherent. A mathematics lesson on graphing quadratic equations might connect with related principles of physics. A science lesson on water cycles might connect with the physical and chemical properties of water and thermodynamics. An engineering lesson might connect chemical engineering with the molecular chemistry of the materials. This indicator assesses the degree to which the teacher connected the **engineering** content in the lesson to other areas of **engineering**, or to other disciplines. For example an engineering lesson on building constraints might connect to the trade-off between, quality, speed, and cost, and evaluate how economics, customer needs, and environmental considerations affect engineering practice.

Although it may seem inappropriate to penalize a teacher for not incorporating these types of connections into every single lesson they teach, it is important that we identify the degree to which these behaviors are present. If absolutely no connections between the concepts being learned and other disciplines or other areas of **engineering** are made during the class period, this indicator should be rated a 1. The indicator should be rated a 1 in this situation even if you feel such connections would not be appropriate or possible for this particular lesson.

General Rubric

1. This item should be rated a 1 if no connections were made to other areas of **engineering** or other academic disciplines or if connections were made that were inappropriate or incorrect.
2. This item should be rated a 2 if a minor connection was made to another area of **engineering** or to another academic discipline, but the teacher did not explicitly discuss this connection with the class.
3. This item should be rated a 3 if the teacher connected the content being learned to another area of **engineering** or another academic discipline, and if the teacher explicitly brought this connection to students' attention.
4. This item should be rated a 4 if the teacher included one or more connections between the content and other areas of **engineering**, other academic disciplines, or problems that professionals might actually encounter, AND the teacher engaged the students in an extended discussion or activity relating to these connections.

5. This item should be rated a 5 if, throughout the class period, the content was taught in the context of its use in other academic disciplines, other areas of **engineering**, or in the work of professionals, and the teacher clearly demonstrated deep knowledge about how the content is used in those areas.

Specific Examples of Supporting Evidence (Engineering)[7]

1. In this lesson the students were discussing problems and solutions of student-created time-keeping instrument designs. The devices were created to measure periods of time that were greater than or equal to one second and less than or equal to two seconds. The device had to run on its own for at least 30 seconds without assistance and they were not allowed to spend more than $10 on the project. There was no attempt to connect these ideas to other areas of engineering or to other disciplines.
2. In this lesson the students were discussing problems and solutions in their instrument design previously mentioned. The teacher had the students use their instrument to measure time and briefly mentioned how physicists could use these instruments, or something like it in their field, but the connection and concepts were largely ignored for this lesson.

[7] This example was based on a project that a science and engineering teacher created for use in her class. This project is for a science classroom but the students follow the engineering design process to develop and build a device that will keep track of small amounts of time accurately. Used with permission from the teacher.

3. In this lesson the students were discussing problems and solutions in their instrument design. After they finished they were asked to identify how they saw Newton's Laws of Motion at work in their project. They were given each law and asked for two examples of how each law was or was not applicable to there project.
4. After completing the lesson described above, they also were asked to identify and describe the energy conversions (e.g. chemical, potential, mechanical etc.) that occurred in their design. After completing the assignment they used their answers to discuss the science behind the design of such an instrument and how the instrument could be used in a scientific laboratory. The teacher led the class in a discussion about engineering design finding systematic solutions to problems based on scientific knowledge and how those solutions can in turn lead to more accurate scientific knowledge.
5. The engineering project was anchored in the context of designing a scientific instrument to be used in scientific laboratory and based upon scientific principles. Students were integrating concepts from physics, chemistry, algebra, and other engineering courses and projects into a large design project. The teacher prompted them to remain aware of the scientific and mathematical applications inherent in the project as well as engineering as a whole. She was able to easily guide the students in discussions and answer

questions about these applications in the classroom. The project lent itself to innate connections to other contents and fields because of the constraints, and specifications provided by the teacher.

4.8 Content Societal Impact: During the lesson, there was discussion about the content topic's role in history or current events.

Concepts in **engineering** are continuously being developed, validated, revisited, and modified based on human society's changing body of knowledge, as events unfold in the world. This indicator assesses the degree to which the teacher discusses or helps students develop their thinking about the historical development of concepts in **engineering**, as well as how concepts from **engineering** are important to current events, current human activity, and current decision-making.

For example, a lesson about rocket **engineering** might include a discussion on the cultural and/or political structure of 13th century China and how these structures might have influenced development of an **engineering** design method. This discussion might also include methods employed by NASA to develop and employ rockets, their successes and failures, and how they affect modern society. Finally, the discussion or activity might connect the two different time periods together in order to help the students fully understand the similarities and/or differences between the kind of **engineering** done in 13th Century China compared to what NASA engineers do today.

In the study of **engineering**, students need to understand that the body of knowledge representing these disciplines is the work of human beings who have conducted research while being influenced by their personal habits of mind, the culture in which they lived, recognition of the needs of their society, and the technologies available to them to solve problems.

This indicator also assesses whether the teacher connects **engineering** concepts to non-school (i.e., "real world") contexts. For example, a lesson on customer needs may include research and discussion about how those needs play into the smart phone market. "What do the engineers have to consider when designing the cell phone in your hand?" "What might you change about the phone?" "Why are some companies more successful than others?" etc.

Although it may seem inappropriate to penalize a teacher for not incorporating these connections into every single lesson, it is important that we identify the degree to which these behaviors are present. If absolutely no connections between **engineering** concepts and human events are made during the class period, this indicator should be rated as a 1. The indicator should be rated a 1 in this situation even if you feel such connections would not be appropriate or possible for this particular lesson. If there was some mention of history or current events during the lesson, this indicator should be rated between a 1 and a 5, depending on the quality of the discussion, the depth of knowledge of the teacher about these issues, the timeliness and relevance of the discussion, and the level of student interest.

General Rubric

1. This item should be rated a 1 if there was no discussion about the content topic’s role in history, current events or relevant “real-world” problems during the class period, or if there was a discussion, but it was inappropriate or incorrect.
2. This item should be rated a 2 if a connection was made to history, current events or relevant “real-world” problems that the teacher did not specifically mention or call attention to (i.e., it was written on a worksheet), or if the teacher made a *general* and brief comment about a possible connection to history or current events that was not expanded upon.
3. This item should be rated a 3 if the teacher explicitly calls attention to how the content is specifically connected to history, current events or “real-world” problems but does not fully expand upon this idea with the class in a way that leads to student learning.
4. This item should be rated a 4 if the teacher explicitly calls attention to how the content is connected to history, current events or relevant “real-world” problems and engages the class in an extended discussion of this connection.

5. This item should be rated a 5 if, throughout the class period, the students are doing activities and/or having discussions related to the content topic's role in history, current events or relevant "real-world" problems and if the teacher clearly demonstrates deep knowledge about how this topic is connected and contextualized in history, current events or to the solution of "real-world" problems.

Specific Examples of Supporting Evidence (Engineering) [8]

1. In this lesson the teacher started the class by telling to students to watch a video found here: http://www.engineeringchallenges.org/cms/8996/9221.aspx. After watching the video, the students asked a few questions but the teacher told them that they had to move along to rest of the day's activities. There was no explicit discussion about the connection of the engineering content to history, current events, or "real world contexts."

2. Before watching the video above, the teacher told the students to think about how these topics might affect practicing engineers, and how they might apply to the "real world". The class watched the video and the teacher made a passing comment about how the Grand Challenges are applicable to what is going on in society and

[8] This example is based upon the National Academy of Engineering Grand Challenges for Engineering linked below. http://www.engineeringchallenges.org/ Accessed July, 2014

the “real world” but there was no focused discussion about the video or topics.

3. Before watching the video above, the teacher told the students to think about how the set of problems presented might affect practicing engineers, and how they might apply to the “real world”. The students were tasked with writing down their ideas during the video for a later discussion. The class watched the video and the teacher then led a discussion about how the Grand Challenges are applicable to what is going on in society and the “real world”. The discussion was brief but the teacher pointed out to the class several connections to how these Grand Challenges matter for current events and in a “real world” context.

4. As a warm-up to begin the class, the teacher asked the students to write down some issues that exist in society that might be able to be solved, at least in part, by engineering. The teacher walked around the class asking questions of students about their suggestions and prodding them to go deeper and think about what is happening in the world right now. The students were charged with taking notes over the video for a later discussion. The class watched the video and the teacher then led a discussion about how the Grand Challenges are applicable to what is going on in society and the “real world”.

5. As a warm-up to begin the class, the teacher asked the students to write down some issues that exist in society that might be able to be solved, at least in part, by engineering. The teacher walked around the class asking questions of students about their suggestions and prodding them to go deeper and think about what is happening in the world right now. The students were charged with taking notes over the video for a later discussion. The class watched the video and the teacher then led a discussion about how the Grand Challenges are applicable to what is going on in society and the “real world”. The teacher also pointed out the “legacy problems” mentioned in the video from the 19th and 20th centuries and discussed how that influences us today. After he discussion concluded, the students split into groups to research one specific Grand Challenge that they would be using for a project. They were to investigate the historical context that led up to the Grand Challenge today, what solutions have been/are being developed, and then to propose their own solutions based upon their research.

Chapter 5: Application to Practice

"*The end-products of science are explanations and the end-products of engineering are solutions." (*NGSS, Appendix F)

The UTeach*Engineering* program has four outcome dimensions, which are as follows:

1. Develop engineering awareness
2. Develop engineering habits of hind
3. Develop an understanding of the design process
4. Develop knowledge for and of engineering teaching

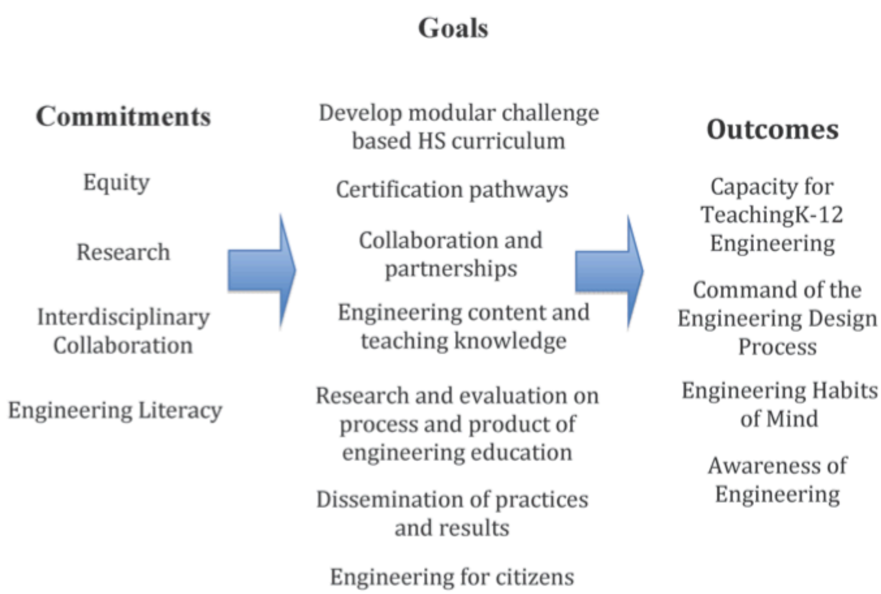

Figure 1. Schematic vision of pre-college engineering education

Figure 3, (Marshall and Berland, 2012, p. 41)

In this section of the report I would like to outline how I feel that this program has succeeded in helping to develop these outcomes in me as a teacher as well as more fully develop me into becoming a teacher leader.

1) Developing engineering awareness: Before embarking upon this program, I had a vague understanding that engineering was different than science and that my friends and family who were engineers did something a little bit different than me when I am in the lab, but I could not have told you what that was. I knew that people stated that engineering was applied science but I didn't really know what that was. As a result of this program, I feel that, not only do I understand much more about what engineering is, I could now point to many of the ways in which it overlaps, intertwines, and diverges from other fields such as science. Next year, as a result of this degree I have been asked to teach both science and engineering at my school. I feel like I not only have the preparation to begin to accurately represent engineering as a field but the tools, resources, and thought paradigms to investigate the field more in depth. In fact, the first project that my co-teacher and I are creating for next year is a career project where our incoming freshmen can investigate current science and engineering careers and education to focus and drive the rest of the course in the school year.

2) Develop Engineering Habits of Mind: As mentioned previously, I was not very familiar with engineering as a practice or a concept before this program, but this program produced a paradigmatic shift in my thinking. I thought of questions many times only through the lens of the scientific method. Many times this manifested as a focus on learning for learning's sake and the idea of answering questions just because they existed. This program, however, has helped me, or at least given me the ability to, think like an engineer. My wife can attest to how often I make a statement now about how well or poorly engineered I evaluate something to be. I now look at things differently while using them and think about how an engineer might have designed this with ergonomic considerations and what inputs and outputs they may have considered among other considerations. This program has not limited my ability to think like a scientist, but rather expanded the depth of it allowing me to apply that thought process to how we might apply what we know to solve a problem. I am really looking forward to modeling this with my students in the coming year. I want to help my students learn and enjoy learning while also seeing that there are multitudinous manners and applications of this new knowledge that we gain, both personally and as a society. I look forward to having rich discussions with my students about both the differences and similarities between engineering and science and how both have their value in today's modern society.

3) Develop an understanding of the design process: From day one in this Master's program we began using the engineering design process; even when I didn't know that we were using it or what it was called. The first day of class Dr. Crawford gave us a bag of various items and said, "Design a toy". We then, without knowing it, walked through many of the steps of the engineering design process, including: Describing the need, analyzing the system, generating and selecting a concept, embodying the concept, and finally sharing the design. It was my first exposure to this idea of the concept that the purpose of engineering was to solve a problem. At every step of this program I was learning, to a greater degree, the implications, purpose and even versatility of the design process. I do not think that I will ever think about engineered objects in the same way as a result.

4) Develop knowledge for and of engineering teaching: Before entering the MASEE program I was unaware of the engineering design process and did not have an inkling as to the effect that it can have on student learning. As mentioned previously, as a result of this program degree, I have been asked to teach engineering next year. Before I started this program I would have never thought it possible that I would ever be asked, or even ever want, to teach engineering. Now not only have I been asked, I cannot possibly describe how excited I am to teach this new course next year. This degree and the upper-level engineering courses that I was able to take part in have helped me realize how fully engineering is applied… in everything. It is applied science, math, language etc. I am very excited to implement the practices and habits of mind that I have developed over the last three years and hope to encourage my students to do the same.

In conclusion, I strongly feel that this program has not only exposed me to what engineering is as a practice and a thought paradigm, it has shown me how intimately linked engineering is in every facet of my life. Thanks to Dr. Crawford, I am no longer able to look at moving parts in something without counting the 4-bar linkages that I find. Thanks to Dr. Allen I can no longer step foot into a tall building without wondering about its structural earthquake specifications. As a result of this program, I can no longer use any hand-held devices without thinking about the ergonomic considerations that its engineers must evaluate and how well it works for me as a customer. Although I would by no means consider myself a professional engineer, I certainly understand a bit more about how they think about problems in the world around us.

Appendix 1

This report will be largely focused on the original language of the Mathematics/Science content domain UTOP indicators, which are as follows

Section 4:

4.1 The mathematics or science content chosen was significant, worthwhile, and developmentally appropriate for this course (includes the content standards covered, as well as examples and activities chosen by the teacher).

4.2 Content communicated through direct and non-direct instruction by the teacher is consistent with deep knowledge and fluency with the mathematics or science concepts of the lesson (e.g., fluent use of examples, discussions, and explanations of concepts, etc.).

4.3 Teacher written and verbal content information was accurate.

4.4 Formal assessments used by teacher (if available) were consistent with content objectives (homework, lab sheets, tests, quizzes, etc.).

4.5 Elements of mathematical/scientific abstraction were used appropriately (e.g., multiple forms of representation in science and mathematics classes include verbal, graphic, symbolic, visualizations, simulations, models of systems and structures that are not directly observable in real time or by the naked eye, etc.).

4.6 During the lesson, it was made explicit to students why the content is important to learn.

4.7 Appropriate connections were made to other areas of mathematics or science and/or to other disciplines.

4.8 During the lesson, there was discussion about the content topic's role in history or current events.

Appendix 2

The following table compares the NGSS Framework language to the UTOP Content Indicator language used in the creation of the Engineering Specific Examples.

NGSS Framework Practice	NGSS Framework Student Expectations	UTOP Content Indicator Connection
1 - ***Engineering questions clarify problems to determine criteria for successful solutions and identify constraints to solve problems about the designed world.*** [Both scientists and] ***engineers also ask questions to clarify ideas.***	***Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.***	4.7 Content Interconnections: Appropriate connections were made to other areas of mathematics or science and/or to other disciplines (including non-school contexts).
2 - ***A practice of*** [both science and] ***engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.*** ***Modeling tools are used to develop questions, predictions and explanations; analyze and identify flaws in systems; and communicate ideas. Models are used to build and revise*** [scientific explanations and] ***proposed engineered systems. Measurements and observations are used to revise models and designs.***	***Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits [the evidence or] design criteria.***	4.5 Content Abstraction: Elements of mathematical/scientific abstraction were used appropriately (e.g., multiple forms of representation in science and mathematics classes include verbal, graphic, symbolic, visualizations, simulations, models of systems and structures that are not directly observable in real time or by the naked eye, etc.).
2	***Develop and/or use a model (including mathematical and***	"

	computational) to generate data to [support explanations, predict phenomena]***, analyze systems, and/or solve problems.***	
3 [Scientists and] ***engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.*** ***Engineering investigations identify the effectiveness, efficiency, and durability of designs under different conditions.***	~~[~~Plan an investigation or] ***test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models,*** [supporting explanations for phenomena,] ***or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.***	4.2 Content Fluency: Content communicated through direct and non-direct instruction by the teacher is consistent with deep knowledge and fluency with the mathematics or science concepts of the lesson (e.g., fluent use of examples, discussions, and explanations of concepts, etc.).
3	***Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.***	"
4 - ***Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria—that is, which design best solves the problem within given constraints. Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more***	***Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to*** [make valid and reliable scientific claims or] ***determine an optimal design solution.***	4.5 Content Abstraction: Elements of mathematical/scientific abstraction were used appropriately (e.g., multiple forms of representation in science and mathematics classes include verbal, graphic, symbolic, visualizations, simulations, models of systems and structures that are not directly observable in real time or by the naked eye, etc.).

efficient and effective.		
4	***Evaluate the impact of new data on a*** [working explanation and/or] ***model of a proposed process or system.***	"
4	***Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.***	"
5 – [In both science and] ***engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; solving equations exactly or approximately; and recognizing, expressing, and applying quantitative relationships.*** ***Mathematical and computational approaches enable*** [scientists and] ***engineers to predict the behavior of systems and test the validity of such predictions.***	***Create and/or revise a computational model or simulation of a*** ~~[phenomenon,]~~ ***designed device, process, or system***	"
5	***Use mathematical, computational, and/or algorithmic representations of*** [phenomena or] ***design solutions to describe and/or support claims and/or explanations.***	"
6 - **The** [end-products of science are explanations and the] **end-products of engineering are solutions.**	***Apply scientific ideas, principles, and/or evidence to*** [provide an explanation of phenomena and] ***solve design***	4.7 Content Interconnections: Appropriate connections were made to other areas of

The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics, and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints.	***problems, taking into account possible unanticipated effects.***	mathematics or science and/or to other disciplines.
6	***Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.***	"
7 - ***Argumentation is the process by which evidence-based conclusions and solutions are reached.*** ***In ~~science and~~ engineering, reasoning and argument based on evidence are essential to identifying*** [the best explanation for a natural phenomenon or] ***the best solution to a design problem.*** [Scientists and] ***engineers use argumentation to listen to, compare, and evaluate competing ideas and methods based on merits.*** [Scientists and] ***engineers engage in argumentation***	***Compare and evaluate competing arguments or design solutions in light of*** [currently accepted explanations], ***new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.***	4.8 Content Societal Impact: During the lesson, there was discussion about the content topic's role in history or current events.

when [investigating a phenomenon], ***testing a design solution, resolving questions about measurements, building data models, and using evidence to evaluate claims.***		
7	***Make and defend a claim based on evidence about the*** [natural world or the] ***effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.***	"
7	***Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations)***	"
8 - *[Scientists and]* ***engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.*** ***Communicating information and ideas can be done in multiple ways: using tables, diagrams, graphs, models, and equations as well as orally, in writing, and through extended discussions.*** [Scientists and] ***engineers employ multiple sources to obtain information that is used to***	***Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to*** [address a scientific question] ***or solve a problem.***	4.2 Content Fluency: Content communicated through direct and non-direct instruction by the teacher is consistent with deep knowledge and fluency with the mathematics or science concepts of the lesson (e.g., fluent use of examples, discussions, and explanations of concepts, etc.).

evaluate the merit and validity of claims, methods, and designs.		
8	***Gather, read, and evaluate*** [scientific and/or] ***technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.***	4.1 Content Significance: The mathematics or science content chosen was significant, worthwhile, and developmentally appropriate for this course (includes the content standards covered, as well as examples and activities chosen by the teacher).
8	***Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear ~~in~~*** [scientific and] ***technical texts or media reports, verifying the data when possible.***	"
8	***Communicate*** [scientific and/or] ***technical information or ideas (e.g. about ~~phenomena and/or~~ the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).***	"

Table developed from APPENDIX F – Science and Engineering Practices in the NGSS, March, 2013 Draft and The UTeach Observation Protocol (UTOP) Training Guide, 2013

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Vita

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